ASTRONOMY AND ASTROPHYSICS

20 CVn: simultaneous *uvby* photometry

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Abstract. Simultaneous observations in the four *uvby* filters of the Strömgren photometric system have been collected for the low amplitude δ Sct star 20 CVn and new times of light maxima have been obtained. Some new additional H_β-Crawford data were also collected. Fourier Transform and classical O-C methods are used to analyse the pulsation of this star. Frequency analysis of our data together with the reanalysis of old photometric data sets suggest this star as a monoperiodic pulsator. From the O-C analysis it seems that the period is decreasing with time. Revision of the different data sets available in the literature does not reveal significant changes in the pulsational amplitude of this star. Intrinsic b-y, m_1 and c_1 values are also derived and the physical parameters are determined. In addition, the analysis of the phase shifts and amplitude ratios between observed light and colour variations suggests that 20 CVn is a radial pulsator in the fundamental mode or first overtone.

Key words: stars: variables: δ Scu – stars: individual: 20 CVn – stars: oscillations – techniques: photometric

1. Introduction

20 CVn is a bright and luminous low amplitude δ Sct type star with V=4.^{m}73, ΔV=0.^{m}02, P=0.^{d}1217 and spectral type F3III (Rodríguez et al. 1994). Its variability was first reported independently by Wehlau et al. (1966) and Danziger & Dickens (1966) during the course of photometric observations. Danziger & Dickens (1967) list this star as a new member of the δ Sct group. New photometric observations were collected by Penfold (1971) using the filter V of the Johnson photometric system, Shaw (1976) in BV, Peña & González-Bedolla (1981) in V, Bossi et al. (1983) in V, Chun et al. (1983) in BV and Nishimura et al. (1983) in V. However, the majority of these data sets are too short and scanty to analyse the pulsational behaviour of 20 CVn. The two best data sets are those from Shaw (1976) (with about 783 and 262 measurements in B and V, respectively) and Peña & González-Bedolla (1981) (with about 198 measurements in V). They seem to be good enough to gain some insight into the frequency content. In both cases, the authors suggest that 20 CVn is monoperiodic with a period of P=0.^{d}1217. However, Bossi et al. (1983) (from their own data) suspect the presence of a second pulsational mode of 6.99 cd^{-1} (P_2=0.^{d}143).

In addition, some spectroscopic data were also obtained by different authors: Penfold (1971), Smith (1982), Nishimura et al. (1983), Yang & Walker (1986) and Mathias & Aerts (1996). From his data, Smith (1982) suggests the existence of a beating effect (of about 2 days) caused by a second period modulating the primary one. This leads to a secondary frequency of about 8.7 cd^{-1} (P_2=0.^{d}115). Moreover, Smith (1982) and Yang & Walker (1986) obtained low values for the term 2K/Δm_v (from 42 to 39 Km s^{-1}mag^{-1}, respectively). On this basis, they suggest that the primary pulsation is nonradial. Finally, Mathias & Aerts (1996), from only one cycle of spectroscopic observations and using the moment method, find this star pulsating nonradially with l=3 or 2. Moreover, they suggest the existence of a second mode. In this way, the main aim of this investigation is to clarify the mono or multiperiodic nature of this star on the basis of new and high quality photometric observations.

On the other hand, very few δ Sct stars showing both low amplitudes and a single pulsation frequency are known. Three well studied examples are: τ Peg (Breger 1991), β Cas (Rodríguez et al. 1992) and 28 And (Rodríguez et al. 1993). In all the three cases nonradial pulsation has been suggested on the basis of phase shifts and amplitude ratios between observed light and colour variations (Watson 1988, Garrido et al. 1990). This is quite different to that occurring in the known high amplitude δ Sct stars (Rodríguez et al. 1996) where radial pulsation is always found. Then, 20 CVn promises to be a good object to study. In order to confirm or not the nonradial nature of this star, we have carried out simultaneous *uvby* photometry.

The observations and light curves are described in Sect. 2. In Sect. 3.1 and 3.2, the periodicity of this star is analysed using the Discrete Fourier Transform and classical O-C methods. Revisions about possible long term luminosity amplitude variations and about the stellar parameters of this star are given in Sect. 3.3 and 3.4, respectively. In Sect. 3.5, the nature of radial or nonradial pulsation in 20 CVn is examined on the basis of the phase shifts and amplitude ratios between different colours. Finally, some conclusions are given in Sect. 4.

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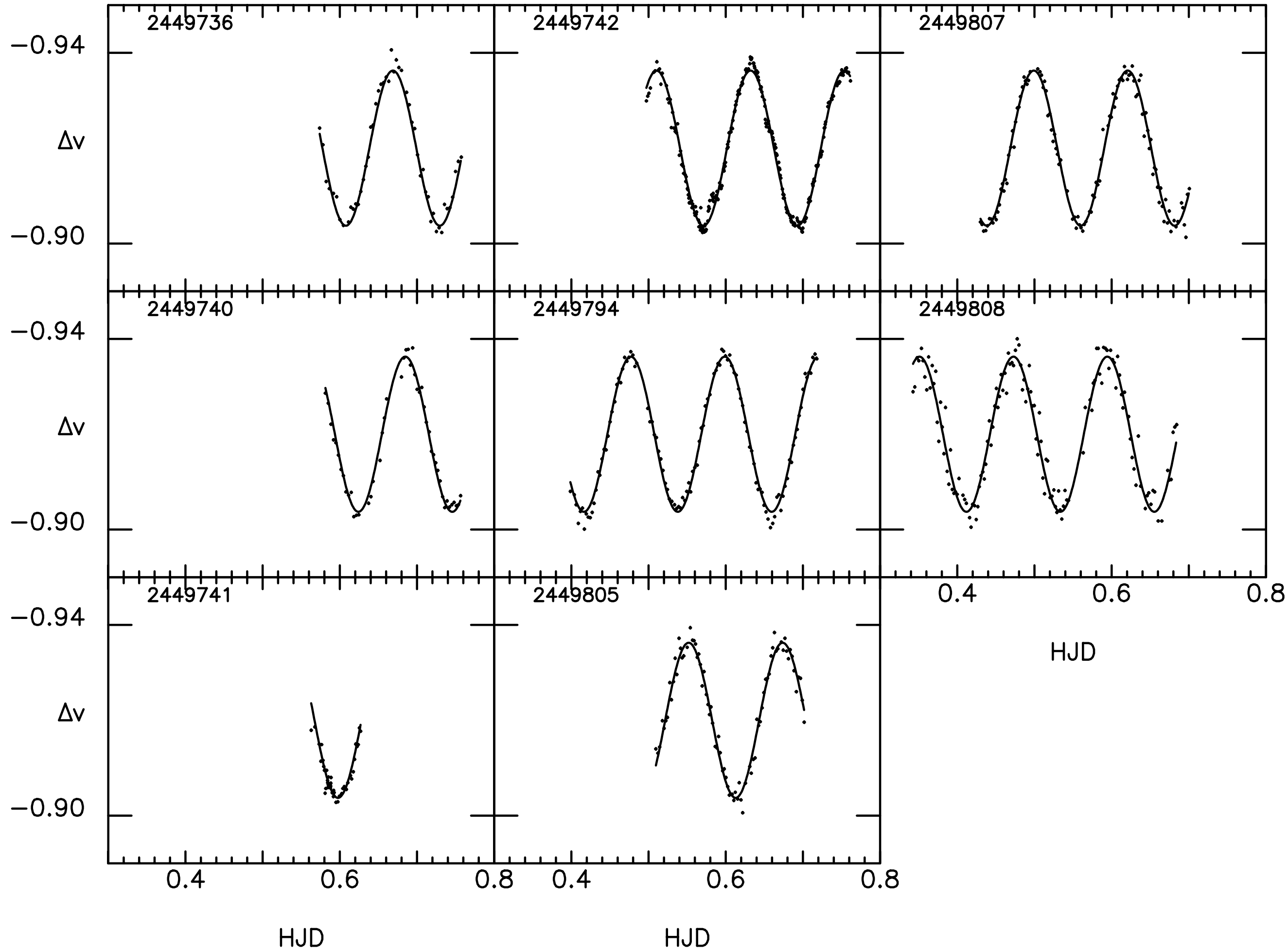

Fig. 1. Observed light curves of 20 CVn in the *v* band with the Fourier fitting versus Heliocentric Julian Day

2. Observations

The observations were carried out on eight nights during January and March, 1995 using the 90 cm telescope at Sierra Nevada Observatory, Spain. The photometer attached to this telescope is a six-channel $uvby\beta$ spectrograph photometer for simultaneous measurements in *uvby* or in the narrow and wide H_β channels, respectively, using uncooled EMI photomultipliers type 9789 QA (Nielsen, 1983).

For these observations, HD 115271 (V=5.^{m}79, A7V) was used as the main comparison star with HD 116127 (V=6.^{m}6, F2) and HD 116303 (V=6.^{m}35, A7) as check stars. The sequence was, generally, C1,C2,star,C1,star. Sky measurements were made every 2 or 3 cycles. C3 was only observed during the two first nights in order to prove the constancy of the comparison stars. 831 *uvby* measurements were collected for the variable, more than 600 for each of C1 and C2 and more than 100 for C3. In addition, some additional data were also obtained in H_β for each of the four objects. Each integration consisted of 30 s. This gives us, for any of the stars, an internal error in each observation better than 0.^{m}0012 in the *u* filter and C2, namely the worst case. This precision is very important for the calibration of the physical parameters and, especially, for the frequency analysis of the variable and to analyse the phase shifts and amplitude ratios between different colours. Also, in the H_β system, each observation consisted of 30 s which yields an internal error better than 0.^{m}0017 in the *n* band and C2, being the worst case.

During the observations reported here, neither of the comparison stars showed any sign of variability. On every night, the standard deviations for C2-C1 differences were always better than 0.^{m}006, 0.^{m}003, 0.^{m}003 and 0.^{m}003 for *u*, *v*, *b* and *y*, respectively. This demonstrates the excellent quality of the sky during this campaign. In addition, the stability of the instrumental system was very good. In fact, the mean values obtained for differences C2-C1 on the eight nights were always the same within 0.^{m}001, as standard deviation, for any of the filters and colour indices.

To transform our data into the standard system we have used the same procedure described in Rodríguez et al. (1997). The data obtained, as magnitude differences variable minus C1=HD 115271 in the standard system versus Heliocentric Julian Day, have been deposited in the Commission 27 IAU Archives of Unpublished Observations, file 332E, and can also be requested from the authors. As an example, the *v* observed light curves are plotted in Fig. 1 with the Fourier fitting obtained in Sect. 3.1.

3. Results

3.1. Frequency analysis

Analysis of frequencies of our data was carried out using the Discrete Fourier Transform method, as described in López de Coca et al. (1984). The *v* filter was the first analysed because both amplitude and intensity are, commonly in δ Sct variables, larger in this band than in all the other three. Firstly, we have analysed the C2-C1 differences. When the Fourier analysis is applied to C2-C1, we obtain C2 and C1 not showing any sign of variability within about $0.^{m}0006$, in the range from 0 to 30 cd^{-1}. The standard deviation of C2-C1 was found to be of $0.^{m}0026$. In our case, the significance level, as defined by Breger et al. (1996), is of about $0.^{m}0010$. That is, the noise level as the average amplitude in an oversampled amplitude spectrum (as defined in Handler et al. (1996)) is of about $2.^{m}25*10^{-4}$ in the same range of frequencies.

When the Fourier analysis is applied to 20 CVn, the periodograms showed a principal peak at ν=8.2168 cd^{-1} in very good agreement with the period P=$0.^{d}1217$ derived by earlier authors. Fig. 2 shows the spectral window and power spectra of 20 CVn in the *v* filter before and after prewhitening for the above derived frequency. The line in the bottom panel of Fig. 2 means the significance level as described by Breger et al. (1996). As can be seen, after prewhitening for the frequency ν, the resulting periodograms did not show any trace of another peak, suggesting the monoperiodic nature of this star within $0.^{m}0005$. Moreover, no signal for the second harmonic of the frequency ν is present in the periodogram. This is due to the very small amplitude of the light curve. Thus, the light curve is a perfect sinusoid. As we can see in Fig. 2, our resulting power spectrum did not show any peak with an amplitude signal-to-noise (S/N) ratio larger than 4 in the range where other peaks may be suspected to be found in this star. The same analysis was performed for the other three *uby* filters and the results were consistent in the sense that the frequency found was always the same within 0.0001 cd^{-1}.

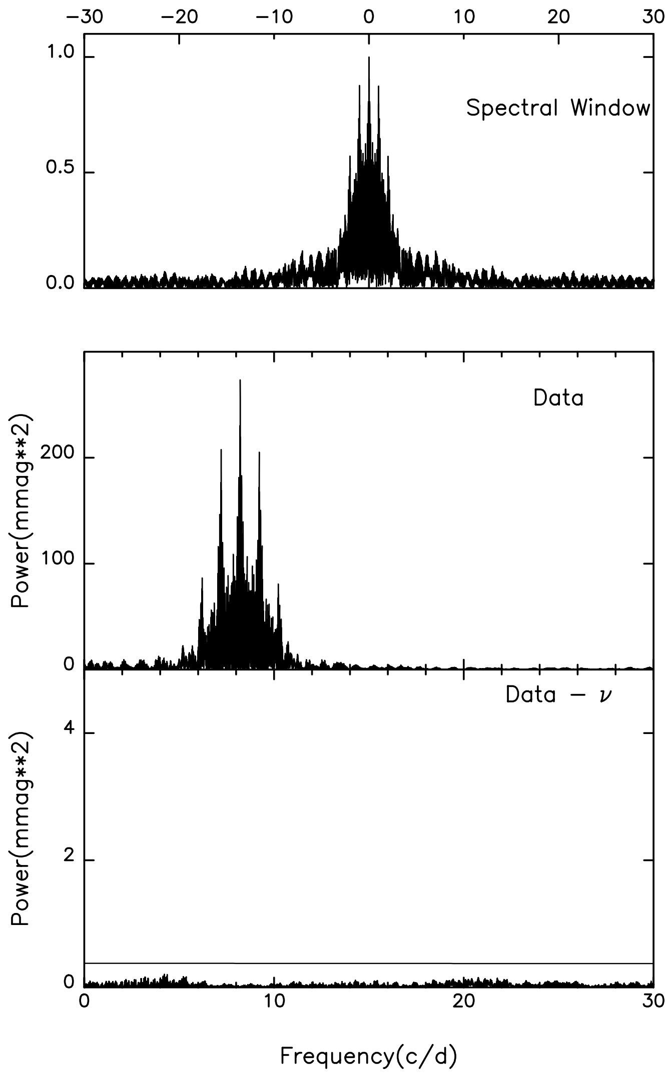

Fig. 2. Power spectra of 20 CVn in the *v filter before and after prewhitening the frequency* ν*=8.2168 cd*$^{-1}$ *to our data*

Frequency analysis was also carried out on the different data sets available from earlier authors, especially on the three best ones, i.e. to the 1969 B and V data of Shaw (1976) and the 1980 V data of Peña & González-Bedolla (1981). In all the cases we find similar results to those found with our data, that is, when the main frequency is prewhitened the resulting periodograms do not show any trace of another peak. Nevertheless, in these cases, the noise level is much higher than in our data. Therefore, we conclude that there are no remaining periodicities in the light variation of 20 CVn.

In our case, the standard deviations, as determined by residuals from the solution, were of $0.^{m}0048$, $0.^{m}0019$, $0.^{m}0017$ and $0.^{m}0018$ for the *u*, *v*, *b* and *y*=V bands, respectively. In Fig. 1 we plot the resulting Fourier fitting, in the filter *v*, with the observed light curves. We can see that the synthetic light curve satisfactorily reproduces the data. The results of the Fourier analysis are listed in Table 1 with the amplitudes, phases, mean values and residuals calculated for the four *uvby* filters together with the b-y and c_1 indices. The initial time is HJD=$2449736.^{d}5738$ which corresponds to our former observational datum.

3.2. O-C analysis

Assuming 20 CVn as a monoperiodic pulsator, the classical O-C method can be used. Twelve times of light maxima were obtained from the new data by using the method described in Rodríguez et al. (1990), where each light maximum was derived as an average over the three *vby* bands. The *u* band was not considered for the averages since the time of maximum for this filter is shifted with respect to the other three by about 0.015 cycles (see Table 1), in agreement with other δ Sct type pulsators (Rodríguez et al. 1995b and references therein). In addition, ten times of maxima have been derived from data of Shaw (1976)

Table 1. Results from Fourier analysis

	u		*v*		*b*		V		b–y		c_1	
H	A (mag)	φ (rad)	A (mag)	φ (rad)	A (mag)	φ (rad)	A (mag)	φ (rad)	A (mag)	φ (rad)	A (mag)	φ (rad)
ν	0.01450	6.195	0.01627	6.097	0.01328	6.100	0.01052	6.096	0.00276	6.115	0.00504	2.663
	23	17	9	6	8	6	9	9	5	19	30	60
mean value (mag)	-0.8686		-0.9200		-1.0020		-1.0603		0.0584		-0.0309	
	2		1		1		1		1		2	
residuals (mag)	0.0048		0.0019		0.0017		0.0018		0.0011		0.0061	
T_{or}(HJD)	2449736.5738											

and Chun et al. (1983) as averages over the BV bands of the Johnson photometric system, another fifteen from Wehlau et al. (1966), Peña & González-Bedolla (1981) and Bossi et al. (1983) in the V band and another one from Nishimura et al. (1983) in the B band. As we can see, the times of maxima are obtained in different filters B, V and *vby* but it is not necessary to correct the different times of maxima to refer all to the same band. These corrections are very small (of about one ten-thousandth of a day) and do not change the final results (Rodríguez et al. 1993). However, the two maxima obtained from Wehlau's et al. (1966) data (HJD=2439278.^{d}722 and 2439293.^{d}688) were not used to determine the ephemeris of 20 CVn. These observations were obtained in nearly the same epoch than those from Shaw (1976) but the instants of these maxima are in disagreement with the ephemeris obtained using different combinations of data sets.

With the aim of using the largest number of maxima as possible to determine the ephemeris of 20 CVn, we made use of the radial velocity data available from the bibliography to calculate the corresponding maxima and to transform to light maxima. For this purpose, we calculate the phase shift between the instants of maximum in radial velocity and light using the spectroscopic data from Mathias & Aerts (1996) and our own photometric data. Note, that these two sets of observations were collected at the same epoch. In this way, we obtain that light maximum occurs after that corresponding to radial velocity by 0.^{d}0443 ($\pm$0.0010)= 131° ($\pm$3). In addition, we can determine the phase shift between the maxima in temperature and radius, assuming the curve in temperature as the curve in (b-y). In this case we obtain $T_{max}(T_e)$-T_{max}(R)=–141° ($\pm$5) in the sense that radius maximum occurs later. Please, note that there is a mistake in the times of the radial velocity curve (Fig. 1) from Mathias & Aerts (1996). The true values were kindly supplied by Mathias (1997, priv. comm.) and a value of HJD=2449707.^{d}6599 was derived for the instant of radial velocity maximum. Using this method, four new times of light maxima were obtained from radial velocity data of Nishimura et al. (1983), Yang & Walker (1986) and Mathias & Aerts (1996).

Consequently, forty times of maxima (from 1969 to 1997), listed in the second column on Table 2, were used to determine the ephemeris of the pulsation of 20 CVn by means of the classical O-C method. At first, we applied this method to the maxima obtained in the epoch 1980-1983. T_0=2444376.^{d}673 (first light maximum derived from Peña & González-Bedolla 1981) was adopted as initial epoch and P_0=0.^{d}12170 (from our Fourier analysis) as the initial period. A least squares fit of a linear ephemeris leads to the following elements: T_1=2444376.^{d}6765 ($\pm$0.0011) and P_1=0.^{d}1217027 ($\pm$0.0000002). This value seems to be good and the residuals appear to be randomly distributed around zero. For a second stage, we applied the O-C method to all the forty maxima listed in Table 2 using as initial ephemeris the above solution T_1 and P_1. Now, the resulting elements of the new linear ephemeris are: T_2=2444376.^{d}6644 ($\pm$0.0024) and P_2=0.^{d}12170234 ($\pm$0.00000008). The resulting cycles E_i and residuals $(O\text{-}C)_l$ are listed in the third and fourth columns of Table 2. The standard deviation of the fit is of 0.^{d}0146. This value is too large and, from Table 2, it can also be seen that the residuals $(O\text{-}C)_l$ are not random distributed around zero. This leads us to make a reinterpretation of all the maxima. A least squares fit of a quadratic ephemeris as $T_{max}=T_3+P_3E+AE^2$ gives the following coefficients: T_3=2444376.^{d}6772 ($\pm$0.0007), P_3=0.^{d}12170268 ($\pm$0.00000002) and A=-19.^{d}3($\pm$0.7)10^{-12}. Now, the standard deviation of the fit is of 0.^{d}0031 in good agreement with the error bars in the determination of the earlier maxima. Moreover, the new residuals $(O\text{-}C)_q$, listed in the fifth column of Table 2, appear to be randomly distributed around zero showing that the residuals $(O\text{-}C)_l$ fit well to the parabola.

This result means that the pulsation period of 20 CVn is decreasing at a rate of dP/dt=-11.6($\pm$0.4)10^{-8} dy^{-1} or dP/Pdt=-95($\pm$3)10^{-8} y^{-1}. However, an observed negative period change is in contradiction with the theoretical positive period changes expected from stellar evolutionary tracks inside the δ Sct region in the H-R diagram, assuming that other physical reasons for period changes can be excluded (Rodríguez et al. 1995a). In particular, for 20 CVn, a star near to the overall contraction phase (using an evolutionary model with core overshooting), the period change rates expected from evolutionary tracks at the two stages considered in Sect. 3.4 (i.e., main sequence and post-main sequence stages using the evolution models of Schaller et al. 1992) were calculated. The results indicate increasing periods with values, for dP/Pdt, of 0.39x10^{-8} y^{-1} and 52.4x10^{-8} y^{-1},

Table 2. Times of maxima of 20 CVn. The sources are: 1) Shaw 1976; 2) Peña & González-Bedolla 1981; 3) Bossi et al. 1983; 4) Chun et al. 1983; 5) Yang & Walker 1986; 6) Nishimura et al. 1983; 7) Mathias & Aerts 1996; 8) present work

i	T_i(HJD) 2400000.+	E_i (cycles)	$(O–C)_l$ (days)	$(O–C)_q$ (days)	Source
1	40296.815	-33523	-0.0219	-0.0016	1
2	40297.671	-33516	-0.0178	0.0024	1
3	40297.791	-33515	-0.0195	0.0007	1
4	40303.641	-33467	-0.0112	0.0089	1
5	40303.756	-33466	-0.0179	0.0022	1
6	40332.713	-33228	-0.0261	-0.0063	1
7	40337.825	-33186	-0.0256	-0.0059	1
8	44376.673	0	0.0086	-0.0042	2
9	44376.796	1	0.0099	-0.0029	2
10	44377.649	8	0.0110	-0.0018	2
11	44377.775	9	0.0153	0.0025	2
12	44378.746	17	0.0126	-0.0002	2
13	44380.694	33	0.0134	0.0006	2
14	44381.665	41	0.0108	-0.0020	2
15	44382.763	50	0.0135	0.0006	2
16	45040.441	5454	0.0120	-0.0021	3
17	45040.565	5455	0.0143	0.0002	3
18	45043.494	5479	0.0225	0.0084	3
19	45043.611	5480	0.0178	0.0037	3
20	45044.462	5487	0.0168	0.0028	3
21	45070.133	5698	0.0086	-0.0055	4
22	45084.130	5813	0.0099	-0.0042	4
23	45359.184	8073	0.0166	0.0023	5
24	45399.224	8402	0.0165	0.0022	4
25	45472.974	9008	0.0149	0.0006	6
26	45473.094	9009	0.0132	-0.0011	6
27	45473.217	9010	0.0145	0.0002	6
28	49707.704	43804	-0.0097	-0.0004	7
29	49736.6699	44042	-0.0090	0.0007	8
30	49740.6844	44075	-0.0107	-0.0009	8
31	49742.5111	44090	-0.0095	0.0003	8
32	49742.6323	44091	-0.0100	-0.0002	8
33	49794.4769	44517	-0.0106	-0.0003	8
34	49794.5987	44518	-0.0105	-0.0002	8
35	49805.5512	44608	-0.0112	-0.0007	8
36	49805.6728	44609	-0.0113	-0.0008	8
37	49807.4998	44624	-0.0099	0.0006	8
38	49807.6206	44625	-0.0108	-0.0003	8
39	49808.4742	44632	-0.0091	0.0014	8
40	49808.5946	44633	-0.0104	0.0001	8

respectively. However, we know that negative period changes are observationally shown for a number of evolved Population I high amplitude δ Sct stars. Nevertheless, the rate of decreasing period found for 20 CVn is also too high, as compared with those observed rates, in about one order of magnitude. Moreover, as we mentioned above, the two maxima derived from Wehlau's et al. (1966) data do not fit well to our resulting ephemeris. Then our result must be used with caution and more data are necessary during the next years in order to get a definitive conclusion.

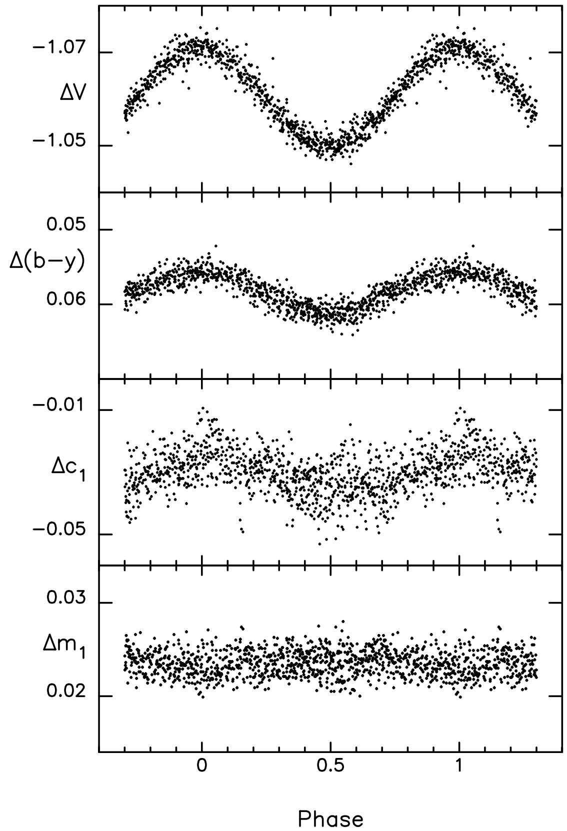

Fig. 3. Light curve and colour index variations of 20 CVn along the pulsation cycle

3.3. Amplitude variations

Long term amplitude variations seem to be common in low amplitude δ Sct stars. This is different to that suspected in the high amplitude ones. For any of the known high amplitude δ Sct stars, long term amplitude variability had not been established at the time. In this sense, we have analysed the different data sets available for 20 CVn from the bibliography. Unfortunately, only the two early data sets from Shaw (1976) in BV and Peña & González-Bedolla (1981) in V are reliable for this subject. Table 3 lists the amplitudes from these data sets together to the one obtained from our data. In all the cases, these amplitude determinations were carried out making the Fourier fitting with only one term for the frequency 8.2168 cd^{-1} obtained in Sect. 3.1. For the sake of homogeneity, Johnson's B amplitude, from Shaw (1976) data, has been transformed to V equivalent amplitude using our *uvby* data and assuming that the *b* and *v* measurements can be averaged to approximate the variations in B. Then, a factor of 0.709 ($\pm$0.011) can be applied to transform B to V amplitudes. From Table 2 it seems that there are not significant variations in the luminosity amplitude of 20 CVn. If there is some real change from one session to another, this variation would be of only a very low percentage of the total amplitude. Nevertheless, only three sessions (years 1969, 1980 and 1995) are available for this analysis. Hence, more data sets are necessary to obtain a definitive conclusion.

3.4. Photometry

Fig. 3 shows the light and colour index variations of 20 CVn along the pulsational cycle assuming the quadratic ephemeris derived in Sect. 3.2. As can be seen, the curves in V and b-y are phased. However, the maximum in the c_1 index curve occurs about 0.05 cycles later than the maximum in b-y, in good agreement with other δ Sct pulsators (Garrido & Rodríguez 1990), due to the temperature and gravity variations. The m_1 index curve seems to be constant, as was expected, from the low luminosity amplitude of this star.

In order to discuss the pulsational characteristics of this star it is useful to know its physical parameters. The following Strömgren values of V=4.^{m}73, b-y=0.^{m}180, m_1=0.^{m}231, c_1=0.913 and β=2.^{m}778 (Rodríguez et al. 1994) were assumed for the variable. The intrinsic indices were derived using the reference lines of Philip & Egret (1980) with the appropriate corrections in gravity and metallicity (Crawford 1975a,b; Philip et al. 1976). Thus, a colour excess of 0.^{m}022, -0.^{m}007 and 0.^{m}005 were found for b-y, m_1 and c_1. Then, deviations from the ZAMS's values of δm_1=-0.^{m}043 and δc_1=0.^{m}172 are obtained. This value for δm_1 indicates that 20 CVn is overabundant in metals. In this case, it has been shown that the c_1 index is not a good luminosity indicator (Kurtz 1979): the luminosity determined directly from δc_1 index is underestimated. It is similar to that shown in Fig. 1 of Rodríguez et al. (1994) where some Am δ Sct stars seem to lie outside of the cool border of the δ Sct region. Fortunately, Guthrie (1987) derived a relation to correct δc_1 in order to be useful as luminosity indicator. This relation depends on metallicity and rotational velocity. In our case, the rotational velocity term can be neglected because the value of *vsini* for 20 CVn is very small (15 Km/s, Rodríguez et al. 1994). Then, its contribution is less than one thousandth of a magnitude.

With these corrections and using the relation by Crawford (1975b) for luminosity, Code et al. (1976) for bolometric correction and the grids by Lester et al. (1986) with [Me/H]=0.0 for temperature and gravity we obtain the following values of M_{bol}=1.^{m}01, T_e=7540 K and log g=3.54. In addition, a value of [Me/H]=0.54 is obtained using the Smalley's (1993) calibration for metal abundances. From a comparison with the (Δm_1^*,β) grids by Rodríguez et al. (1991), a m_1 index variation of less than 0.^{m}001, reversed with respect to the V light curve, must be expected over the full cycle of pulsation of 20 CVn. This expected variation is too small to be detected from the m_1 index curve as it can be seen in Fig. 3.

The values found for T_e, log g and [Me/H] are in good agreement with those compiled in the Cayrel de Strobel's et al. (1992) catalogue from earlier authors. This is also true for [Me/H]=0.48 obtained by Hauck et al. (1985). However, our determinations for T_e and log g seem to be higher than those of 7200 K and 3.0 obtained by these authors from spectrograms. In order to decide this point, we have reanalysed our data. As mentioned in Sect. 2, a few H_β measurements were collected in this work. Then, the standard magnitude differences of 20 CVn minus C1=HD 115271 were transformed to apparent magnitudes of the variable assuming the following values for C1: V=5.^{m}79, b-y=0.^{m}109, m_1=0.^{m}205, c_1=0.^{m}943 and β=2.^{m}856 (Hauck & Mermilliod 1990). Then, we obtain the following Strömgren indices for 20 CVn: V=4.^{m}73, b-y=0.^{m}168, m_1=0.^{m}231, c_1=0.912 and β=2.^{m}798 in very good agreement with our previous determination. Only there are some differences in b-y and β but they indicate a hotter and, hence, less luminous star. Following the same procedure mentioned above, we obtain: M_{bol}=1.^{m}33, T_e=7760 K, log g=3.73 and [Me/H]=0.47. Then, we assume the mean values of 1.^{m}17, 7650 K, 3.64 and 0.51 for these parameters, with typical errors of 0.^{m}3, 150 K, 0.1 and 0.1, respectively (Lester et al. 1986; Breger 1990; Smalley 1993), in good agreement with the values derived above.

Table 3. Amplitudes, as determined by means of the Fourier analysis (i.e., semiamplitudes), on different data sets. The sources are: 1) Shaw 1976, 2) Peña & González-Bedolla 1981, 3) present work

Year	Filter	Amplitude (mag)	V Equivalent Amplitude (mag)	Source
1969	B	0.0143	0.0101	1
		4	4	
1969	V	0.0099	0.0099	1
		8	8	
1980	V	0.0109	0.0109	2
		4	4	
1995	V	0.0105	0.0105	3
		1	1	

Moreover, using the relation by Petersen & Jørgensen (1972), a value of Q=0.^{d}028 ($\pm$0.005) (Breger 1990) is found for the pulsation constant. This indicates that 20 CVn is pulsating in the fundamental mode or first overtone assuming radial pulsation. Finally, it is possible to gain some insight into the mass and age of this star using the evolutionary tracks of Schaller et al. (1992) for Z=0.020. This way, a mass of 2.16($\pm$0.1) $M_\odot$ and age of 1.0($\pm$0.2) 10^9 years can be obtained in a post-main sequence stage of evolution. When a main-sequence stage is considered for 20 CVn, a mass of 2.33 $M_\odot$ and age of 0.7 10^9 years are found.

3.5. Pulsation mode identification

Due to only one frequency being found in the light curve of 20 CVn, methods based on period ratios or frequency differences are excluded in order to identify the pulsation mode of this star. However, the methods based on the phase shifts and amplitude ratios between the observed light and colour variations, in *uvby* photometry (Garrido et al. 1990) or in UBV photometry (Watson 1988), can be used to determine the nature of radial or nonradial pulsation in this star and to identify the mode in which 20 CVn is oscillating. This point is of interest because this star has also been observed by other authors (Mathias & Aerts 1996) at high resolution spectroscopy and found as a nonradial pulsator, possibly a tesseral l=3 or a sectorial l=2 mode with |m|=2, using the moment method.

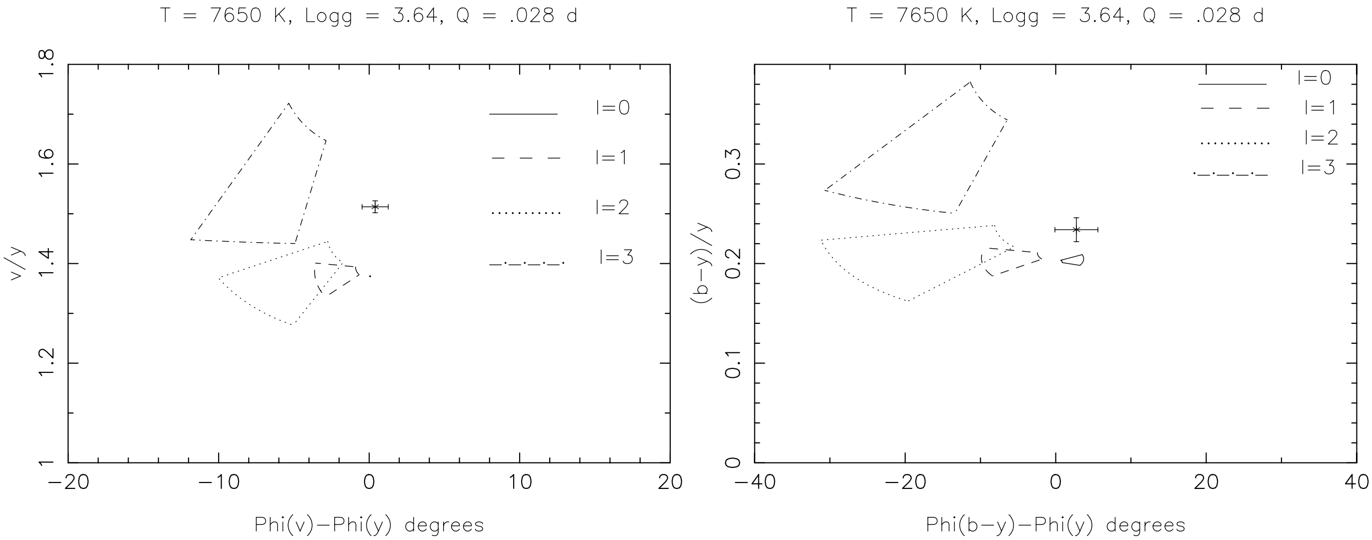

Fig. 4. a Observed phase shift and amplitude ratio between the *v* and *y* filters for 20 CVn. The predictions of the model, for T_e=7650 K, log g=3.64 and Q=0.^{d}028, are also shown for l=0,1,2,3. **b** Same as **a** for b-y and *y*

Table 4 lists the phase shifts, in degrees, and amplitude ratios between the different bands and colour indices, as resulting from Table 1. We can see that the phase shifts of both *v* and *b* filters with respect to the *y* band are nearly zero, allowing only small positive or negative values. This is also true for the pair (b-y,y). These effects suggest radial pulsation for this star by comparing with the "amplitude ratios versus phase shifts" diagrams of Garrido et al. (1990). However, the figures given by these authors refer to a δ Sct model with T_e=8000 K [or 7850 K in the (b-y,y) diagram], log g=4.0 and Q=0.^{d}030. With the aim of deciding this point we have calculated the regions of interest for a model with the appropriate parameters (T_e=7650 K, log g=3.64, Q=0.^{d}028) for this star. Figs. 4a, b show the predictions of this model for l=0, 1, 2, 3 and the (v,y) and (b-y,y) pairs. These graphs again suggest radial pulsation for 20 CVn, although the amplitude ratios seem to be slightly large especially for Δv/Δy. However, we consider this disagreement to be minor, since the amplitude ratios (but not the phase shifts) are sensitive to the adopted atmospheric parameters (Breger 1997a,b). In fact, our results lead to the same conclusions when we take into account the error bars in T_e, log g and Q. In addition, radial pulsation is also suggested from phase shifts in UBV photometry (Watson 1988) using the data set of Shaw (1976). Only these observations are available in the bibliography with measurements in both B and V filters. We obtain ϕ_B-ϕ_V=1.°8 ($\pm$5.7), ϕ_{B-V}-ϕ_V=5.°8 ($\pm$8.6), ΔB/ΔV=1.44 ($\pm$0.16) and Δ(B-V)/ΔV=0.44 ($\pm$0.12). In this case, the error bars are larger but the results agree well with our conclusions in *uvby* photometry.

The question now arises when interpreting the high resolution spectroscopy results of Mathias & Aerts (1996). They find that 20 CVn is a multiperiodic variable pulsating in a nonradial mode with l=3 or 2. Their data seem to be of very high quality but, we feel they collected a too small amount of data to get a definitive conclusion. In fact, they have observations of only one pulsational cycle. Nevertheless, nonradial pulsation in 20 CVn was also suspected by Smith (1982) and Yang & Walker (1986). In the former case, Smith (1982) used the classical method which consists of a comparison between the observed spectrum and a theoretically computed one on a trial-and-error basis. This author found that on profile fitting alone the radial pulsation solution can not be ruled out for the primary mode of 20 CVn. Then, his nonradial suggestion is based in two other points: 1) multiperiodic behaviour and 2) low value of 2K/Δm_v for the main pulsation. This last point is also the one pointed out by Yang & Walker (1986). With respect to the first point we now know that this star is a monoperiodic pulsator, at least from a photometric point of view. In relation to the second point, Smith (1982) found a value of 2K/Δm_v=42 Km s^{-1}mag^{-1} for 20 CVn assuming 2K=1.3 Km s^{-1} and Δm_v=0.^{m}03 (full light amplitude in the V band). However, we now know that Δm_v=0.^{m}0207 (mean value from Table 3). Moreover, from earlier authors, the value of 2K ranges from 1.2 (Yang & Walker 1986) to 1.7 (Nishimura et al. 1983). Then, the ratio 2K/Δm_v ranges from 58 to 82 Km s^{-1}mag^{-1}. These values are not a strong indication of nonradial pulsation. Similar values of 2K/Δm_v=84 Km s^{-1}mag^{-1} were also found by Smith (1982)

Table 4. Observed phase shifts and amplitude ratios

u-y (°)	v-y (°)	b-y (°)	(b-y)-y (°)	c_1-y (°)
5.7	0.1	0.2	1.1	-16.7
1.4	0.8	0.8	1.6	3.9

u/y	v/y	b/y	(b-y)/y	c_1/y
1.38	1.55	1.26	0.26	0.48
3	2	2	1	3

for the radial primary mode of δ Sct and δ Del. Furthermore, to use the 2K/Δm_v ratio to discriminate safely between radial and nonradial pulsation is subject of controversy (see e.g., Riboni et al. 1994 and references therein). In summary, we feel that radial pulsation is the most reliable identification for the pulsational nature of 20 CVn.

However, taking into account the spectroscopic results of Smith (1982) and Mathias & Aerts (1996) it might be that the spectroscopic and photometric behaviour of this star is different. In this sense, and in order to accurately identify the mode(s) and to decide on the mono/multiperiodic behaviour of 20 CVn, it would be very interesting to perform a long campaign to observe this star collecting simultaneously high resolution spectroscopy and multicolor photometry.

4. Conclusions

In this work we have carried out a photometric study of the low amplitude δ Sct star 20 CVn based on simultaneous *uvby*β observations collected during the year 1995. Frequency analysis to our data together with the reanalysis of old photometric data sets suggest this star as a monoperiodic pulsator in which only the first harmonic is present. Intrinsic Strömgren values have been derived and the physical parameters of this star were determined and compared with those obtained by earlier authors. The analysis of the phase shifts and amplitude ratios between observed light and colour variations, using both *uvby* and UBV photometry, suggests radial pulsation in the fundamental mode or first overtone for 20 CVn. Nevertheless, taking into account the spectroscopic results from earlier authors, it would be very interesting to investigate the behaviour of this star with simultaneous spectroscopic and multicolor photometric observations.

In addition, the classical O-C method has been used in order to study the behaviour of the period suggesting that it is decreasing with time during the last three decades, but the value found for the period change is too large as compared with those observed for other δ Sct stars. Revision of the different data sets available from bibliography does not reveal significant changes in the luminosity amplitude of this star from one session to another. However, in these last two aspects more observations are needed over the coming years to get more definitive conclusions.

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